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Section: Original Investigation

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Authors: Athanasios Chatzinikolaou,¹ Konstantinos Michaloglou,¹ Alexandra Avloniti,¹ Diamanda Leontsini,¹ Chariklia K. Deli,² Dimitris Vlachopoulos³, Luis Gracia-Marco,^{3,4} Sotirios Arsenis,¹ Ioannis Athanailidis,¹ Dimitrios Draganidis,² Athanasios Z. Jamurtas,² Craig A. Williams,^{3,5} and Ioannis G. Fatouros,²

Affiliations: ¹Democritus University of Thrace, School of Physical Education and Sport Sciences, Komotini, 69100, Greece; ²University of Thessaly, School of Physical Education and Sport Sciences, Karies, Trikala, 42100, Greece; ³Children’s Health and Exercise Research Centre, Sport and Health Sciences, University of Exeter, United Kingdom; ⁴Growth, Exercise, Nutrition and Development Research Group, University of Zaragoza, Zaragoza, Spain; ⁵Royal Devon and Exeter NHS Foundation Trust Hospital, Exeter, U.K.

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¹Democritus University of Thrace, School of Physical Education and Sport Sciences, Komotini, 69100, Greece; ² University of Thessaly, School of Physical Education and Sport Sciences, Karies, Trikala, 42100, Greece; ³Children's Health and Exercise Research Centre, Sport and Health Sciences, University of Exeter, United Kingdom; ⁴Growth, Exercise, Nutrition and Development Research Group, University of Zaragoza, Zaragoza, Spain; ⁵Royal Devon and Exeter NHS Foundation Trust Hospital, Exeter, U.K.

Running head: Complex training during adolescence

Contact details:

Ioannis G. Fatouros
School of Physical Education and Sports Sciences
University Campus,
Trikala, Karies, 42100, Greece,
Tel +30-24310-47055,
E-mail: ifatouros@pe.uth

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Purpose: To investigate the effect of a complex, short-term strength/power training protocol on performance and body composition of elite early-adolescent soccer players. **Methods:** Twenty-two players (14-15 years) were randomly assigned to (a) an experimental (EG, n=12, participated in a 5-week training protocol with traditional multi-joint power resistance exercises, Olympic-style lifts, plyometric drills and speed work, four times/week) or (b) a control group (CG, n=10). Strength and power performance [jumping, speed, change of direction, repeated sprint ability, endurance, isokinetic strength of knee flexors and extensors, maximal strength in various lifts, speed-endurance) were evaluated pre- and post-training. **Results:** Cessation of training for five weeks in the CG induced a marked performance deterioration (~5-20%). Training not only prevented strength performance deterioration but also increased it (~2-30%). Endurance and RSA declined to a smaller extent in EG compared to CG (15% vs. 7.5%). Isometric strength, and body composition remained unaltered in both groups. **Conclusions:** Results demonstrate that (i) young players exhibit a high level of trainability of their strength/power performance (but not endurance) in response a short-term complex training protocol during early adolescence, (ii) Olympic-style lifts are characterized by increased safety in this age group and appear to be highly effective, (iii) it appears that lifts incorporating a hip thrust result in increased strength of both knee extensors and flexors, (iv) cessation of training for only five weeks results in marked deterioration of strength/power and endurance performance and (v) improvement of strength/power performance may be related to neural-based adaptation since body composition remained unaffected.

Keywords: association soccer, adolescence, weight training, plyometrics, body composition

ST utilizing higher loads at lower velocities with traditional resistance training exercises (e.g. squat) although they are effective in enhancing lower-body strength they may not increase strength optimally at higher velocities characterizing powerful sport movements.⁹ The latter requires an increase in the rate of force development (RFD) at the ankle, hips and

knees which is better developed by exercises using lower resistance and higher velocities.¹⁰ Ballistic, Olympic-style lifts are performed at higher velocities introducing an acceleration of a lighter weight throughout the lift.¹¹ Although these lifts may result in lower strength development when compared to traditional weight training¹², they induce a higher output in speed-power performance in adolescent athletes¹² with RFD being 4-5-fold greater during these lifts than that measured during a squat.¹³ Utilization of both types of exercise may produce the best improvement of power performance due to an increase in both maximal strength and RFD and it represents the most popular practice among high school, college and professional conditioning specialists particularly during off-season training.¹⁴ On the other hand, soccer skills such as ball kicking and sprinting also rely on the utilization of the stretch-shortening cycle (SSC) to produce rapid force.⁹ Plyometric training (PT) is highly effective in promoting strength, speed and power performance in youth soccer players¹⁵ whereas its combination with resistance or sprint training may be even more effective.¹⁶ Complex training (CT) is a method used to improve both strength and power combining a resistant exercise of slow velocity and heavy load (e.g. squat) with an exercise of higher velocity, lighter load and a similar biomechanical movement pattern (e.g. plyometric jumps).¹⁷ The available information regarding the responses of soccer players to periodized complex strength/power training during early adolescence is limited. Therefore, this study used a comprehensive set of measurements to evaluate the effects of a 5-week periodized strength/power training program consisting of multi-joint, high-intensity resistance exercises, plyometrics, and speed-endurance drills during off-season on (i) soccer-specific performance and (ii) isometric, eccentric and concentric strength of KE and KF. It was hypothesized that a 5-week complex training program will not change the performance of early adolescent soccer players.

2. Methods

Participants. A power analysis, based on previous studies in youth populations of similar research designs,¹⁵ performed before the study using an effect size >0.55, a probability error of 0.05, and a power of 0.9 for two groups and time points (pre, post) indicated that 16 subjects were the smallest acceptable number of participants to analyze the interaction between group and time points of measurements. Initially, 48 males (13-15 years) were approached but 34 volunteered to participate in this investigation. Participants were included in the study if: 1) had no musculoskeletal injuries for ≥ 12 months prior to the study; 2) were early-pubertals (Tanner stage 3); 3) participated in $\geq 95\%$ of training sessions; 4) participated in organized youth soccer training for ≥ 6 years; 5) participation in ≥ 5 practices/week during in-season; 6) had no previous experience of ST with multi-joint exercises; 7) did not consume any medications; 8) medical history (reported by parents/guardians) included no previous growth irregularities. Twenty-two boys met the inclusion criteria and completed the study. Experimental procedures and potential risks, discomforts and benefits were fully explained to all boys, parents/guardians and coaches prior to participation. Signed informed consents were provided by participants' parents and/or legal guardians, the Institutional Ethics Committee approved the study and procedures were in accordance with the Helsinki declaration. Participants' characteristics are shown in Table 1.

Study overview. A randomized, two-group, repeated measures experimental design was employed. Participants were assigned to either a control (CG, N=10, did not train; age 14.1 ± 0.6 years) or an experimental group (EG, N=12 completed training; age 14.3 ± 0.7 years). The study was conducted one week within the off-season period. A familiarization period with experimental/training procedures was utilized to minimize the learning effect error. Four days following familiarization, participants underwent a two-day baseline testing [day 1: anthropometric and strength assessment; day 2: measurement of speed, repeated sprint ability

Training Program

Measurements

Anthropometrics. Body mass was measured to the nearest 0.5 kg (Seca 710, United Kingdom, Birmingham) with subjects wearing the underclothes and bare-footed. Standing height was evaluated to the nearest 0.5 cm (Seca stadiometer 208, United Kingdom, Birmingham). Body composition (% fat), was measured using dual-energy X-ray

Statistical Analyses. Data are presented as means±standard deviation. Data normality was verified by one-sample Kolmogorov–Smirnov test. Data were analyzed by 2-way (trial X time) repeated measures ANOVA on different time points. For post-hoc analysis, a Bonferroni

3. Results

No changes were noted in isometric peak torque of KF and KE of both limbs in the two groups (Figure 3). Changes in isokinetic strength measures at 60°/s are shown in Figure 4. In dominant limb, concentric peak torque of KF remained unaltered by training in both groups, eccentric peak torque of KF decreased in CG (-6.7%, $F_{(1,20)}=25.56$, $p<0.05$, $\eta^2=0.56$) and increased in EG (5.8%, $F_{(1,20)}=25.56$, $p<0.05$, $\eta^2=0.56$), concentric peak torque of KE decreased in CG (-7.2%; $F_{(1,20)}=9.92$, $p<0.05$, $\eta^2=0.33$) and increased in EG (2.1%; $F_{(1,20)}=9.92$, $p<0.05$, $\eta^2=0.33$) whereas both the conventional and functional ratios (Figure 6) remained unaltered in

4. Discussion

This is the first investigation to study the effects of complex-type exercise training on performance of elite early-adolescent soccer players. Results indicate that (i) five weeks only of off-season detraining in the CG induced a deterioration of speed/power and endurance performance which was more pronounced in eccentric strength of KF and concentric strength of KE; (ii) a five-week periodized complex training program not only attenuated the decline of

strength/power performance observed during off-season detraining but also enhanced it; and

(iii) deterioration of endurance performance due to off-season detraining cannot be affected by a strength/power training program.

Cessation of training in the CG during off-season resulted in considerable strength detraining of KE and KF strength at low-speed movements. This reduction of KE strength in CG during off-season was greater than that observed to that of KF in both limbs thereby resulting in greater values of conventional and functional ratios in CG. On the other hand, at high-speed movements eccentric strength of KF and concentric strength of KE demonstrated a greater reduction rate during the same time-frame. These findings suggest that strength deterioration during high velocity motions is mainly seen at knee extensions during which KE contract concentrically and KF act eccentrically. This phenomenon is also supported by the fact that maximal strength in two multi-joint exercises that are heavily rely on eccentric strength of KF and concentric strength of KE (i.e. squat and RDL) was reduced by 8-14% in CG. These findings coincide with previous reports suggesting that young athletes may experience a rapid loss of central adaptations initially and of muscle mass later.²³ Since no changes were observed in body composition, a plausible explanation for these reductions of muscle strength is probably a compromised neural input. Detraining effects on performance are related to factors such as maturation, training level, and total training load before training cessation.²⁴ Short-term detraining in this study induced a decay of maximal force (e.g. 1RM) at a greater extent (8-14% vs. 2-9%) than force during higher velocity movements (e.g. peak torque at 180°/s, jumping, speed and COD). The smaller decline of power performance may be associated with the smaller decay of torque at higher velocities as compared to maximal strength and/or to an upregulation of the expression of fast myosin heavy-chain isoforms in muscle following detraining which may enhance velocity potential to compensate for the reduction in maximal force.²⁵

Speed improvement (~4%) was of similar magnitude with that usually reported for youth exposed to ST.²⁷ However, others failed to observe changes in speed despite a rise in muscle power in response to ST.²⁶ This discrepancy among studies is probably related to differences in the type of exercises used, planes of movements and muscles recruited. We emphasized movement in various planes, recruitment not only of thigh and tibia muscles but also that of the hip at the horizontal vector which seem to be prerequisites for development of speed and acceleration.²⁸ It appears that exercises emphasizing the recruitment of hip musculature such as dead lifts, lunges, and Olympic style lifts may be well-tolerated and effective for adolescent athletes when used in the context of complex training. However, this type of training failed to improve high-velocity movements, i.e. the sprint time at 30 m. It appears that incorporation of lifts characterized by high-velocity and lighter loads such as the Olympic lifts may be effective for strength/power development of adolescent soccer players

during off-season. This type of lifts was found to be more effective than traditional strength exercises four young soccer players.¹²

The complex training protocol used resulted also in improvement of vertical jumping corroborating previous findings in youth.²⁷ It appears that even a moderate rise in maximal strength is associated with a substantial increase in lower limb muscle power²⁹ and participants in this study improved both. Maturation could not have affected these results since the controls demonstrated a different response, the training protocol was of a very short duration, and participants were far from their peak growth period.³⁰

Training cessation during off-season reduced speed-endurance (15% in YO-YO IR2 and 40% in RSA). Training in EG attenuated the deterioration in YO-YO IR2 performance but not that of RSA. In young men, detraining results in reduced endurance performance mainly due to peripheral adaptations (e.g. reduced capillarization of muscle fibers, substrate utilization, mitochondrial energy capacity, electrolyte regulation) even after only 3-4 weeks of detraining.³¹ The complex training model adapted by this study did not affect endurance as it did for strength/power measures indicating a specificity effect.

A number of limitations are associated with this investigation. A lack of measurement of hormonal levels which change abruptly during early adolescence in boys.³² As such, our results can be extrapolated to other groups such as age-matched female athletes or adults. The training intervention was short-lived (5 weeks/20 training sessions) which might have not allowed participants to fully grasp the squat and/or the hip thrust movements of exercises incorporated in the training program. Changes in acceleration were only assessed and not in maximal speed by using only short-distance sprint testing. Although participants were instructed to abstain from strenuous activities, their daily physical activity was not assessed (e.g. with accelerometry).

5. Practical applications

Early-adolescent soccer players demonstrate an exceptional level of trainability to complex strength/power training during the off-season during which no soccer training was implemented. Specifically, only five weeks of this type of training was able to induce considerable gains in measures of strength, power (approximately 2-30%) and soccer specific performance but not endurance. Olympic-type lifts were well tolerated by young players and may contribute to considerable strength and power gains. This type of training protocol appears to work efficiently when applied according to the linear periodization model that uses a progressive increase of workload. Another major finding of the present study is that cessation of training even for 5-6 weeks may induce marked detraining in strength/power (approximately -5 to -20%) and endurance (approximately -8% to -15%) performance.

6. Conclusions

In conclusion, implementation of a periodized complex training protocol consisting of multi-joint lifts, Olympic-style lifts, plyometrics and speed drills in early adolescent soccer players not only offsets the deleterious effect of cessation of training during off-season on strength/power performance but it may also improve it. These results seem to be related mainly to neural adaptations rather than to an increase in muscle mass.

7. Acknowledgments

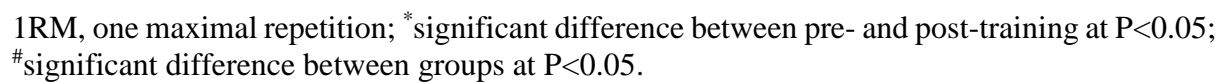
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8. Conflict of Interest

No conflicts of interests to declare.

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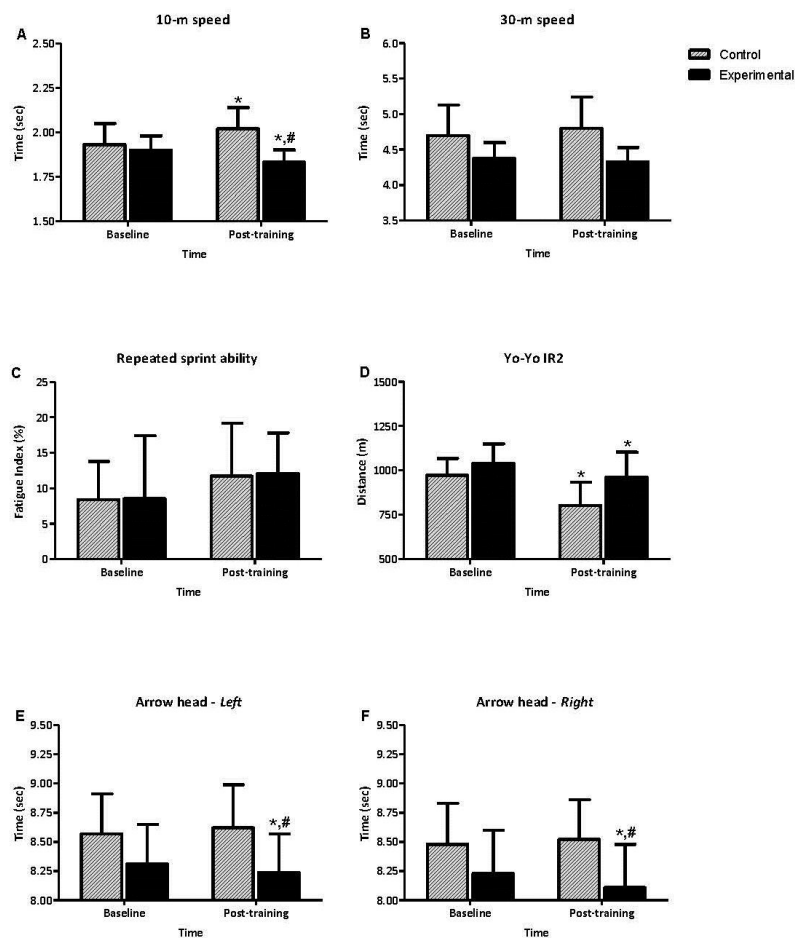
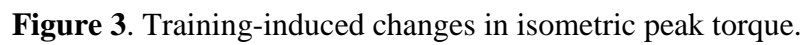
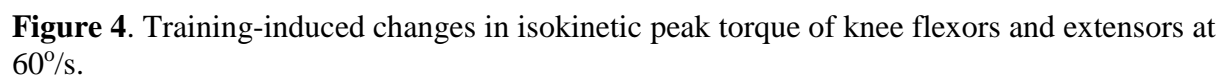


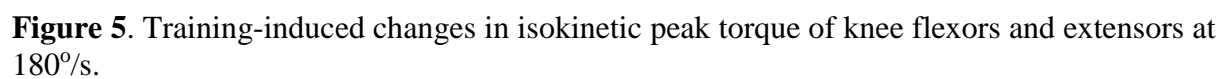
Figure 2. Training-induced changes in speed, speed-endurance and COD measurements.

m, meters; YO-YO IR2, Yo-Yo intermittent recovery test 2; * significant difference between pre- and post-training at $P < 0.05$; # significant difference between groups at $P < 0.05$.

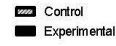




*significant difference between pre- and post-training at $P<0.05$; #significant difference between groups at $P<0.05$.



*significant difference between pre- and post-training at $P<0.05$; #significant difference between groups at $P<0.05$.



KF, knee flexors; KE, knee extensors; * significant difference between pre- and post-training at $P<0.05$; #significant difference between groups at $P<0.05$.

Table 1: Anthropometric results.

		Pre-training	Post-training	F, p, η^2
Weight (kg)	Control	72.24 \pm 8.1	72.06 \pm 8.1	F _(1,20) =0.32
	Experimental	69.13 \pm 5.0	69.1 \pm 5.3	p=0.58 η^2 =0.05
Height (m)	Control	1.78 \pm 0.1	1.78 \pm 0.1	F _(1,20) =1.82
	Experimental	1.79 \pm 0.1	1.79 \pm 0.1	p=0.86 η^2 =0.08
BMI (kg m ⁻²)	Control	22.69 \pm 1.9	22.64 \pm 2.1	F _(1,20) =0.03
	Experimental	21.66 \pm 0.9	21.56 \pm 1.0	p=0.18 η^2 =0.01
% Body Fat	Control	18.18 \pm 4.5	18.21 \pm 4.3	F _(1,20) =0.22
	Experimental	14.26 \pm 2.2 [#]	13.8 \pm 2.7 [#]	p=0.65 η^2 =0.01

*Significant difference with baseline; #significant difference between groups; BMI, body mass index.

Table 2: The training protocol.

Weeks		1	2	3	4	5
Progressions						
Warm up was the same for all training sessions and consist it of muscle activation, low intensity cardiovascular exercise, dynamic stretching, skills exercise and ball possession games. Total duration was 30 min						
TS 1	Exercises:					
	<ul style="list-style-type: none"> Squat Romanian dead lifts (RDL) Lounges One leg –RDL Bench press Rowing Shoulder press Barbell elbow curls Dips 	Intensity: 60-70% Reps: 10-14 Sets: 2 Rest: 60 s	Squat and RDL* Intensity: 70-80% Reps: 10-12 Sets: 3 Rest: 80 s	Squat and RDL Intensity: 70-80% Reps: 8-10 Sets: 3 Rest: 90 s	Squat and RDL Intensity: 80-85% Reps: 6-8 Sets: 3 Rest: 120 s	Squat and RDL Intensity: 80-90% Reps: 6-3 Sets: 2 Rest: 120 s
TS2	Exercises: <ul style="list-style-type: none"> Barbell cleans plus 10-20m sprints or agility drills Kettlebell snatch plus 10-20m sprints or agility drills Box jumps plus 10m agility drills 	Intensity: 20 kg/10 kg/20 cm Reps: 6-8 Sets: 3 Rest: 90-120 s	Intensity: 30 kg/10 kg/30 cm Reps: 6-8 Sets: 3 Rest: 90-120 s	Intensity: 30 kg/10 kg/40 cm Reps: 6-8 Sets: 3 Rest: 90-120 s	Intensity: 40 kg/10 kg/50 cm Reps: 6-8 Sets: 3 Rest: 90-120 s	Intensity: 40 kg/10 kg/50 cm Reps: 6-8 Sets: 3 Rest: 90-120 s
TS3	Exercises: <ul style="list-style-type: none"> Squat RDL Step ups in box One leg RDL Bench press Inverse rowing Dumbbells shoulder extensions Cable elbow flexions 	Intensity: 60-75% Reps: 10-14 Sets: 2 Rest: 60-80 s	Squat and RDL* Intensity: 70-80% Reps: 10-14 Sets: 2 Rest: 60-80 s	Squat and RDL Intensity: 70-80% Reps: 10-14 Sets: 2 Rest: 60-80 s	Squat and RDL Intensity: 80-90% Reps: 10-14 Sets: 2 Rest: 60-80 s	Squat and RDL Intensity: 80-90% Reps: 10-14 Sets: 2 Rest: 60-80 s

*For the rest exercises training load was stable throughout the experimental design. TS 1: first training session of the week - strength training in gym; TS2: second training session of the week - Power training in soccer pitch; TS3: third training session of the week - strength training in gym; TS4: fourth training session of the week - Power training in soccer pitch; s, seconds.